SIMULATION OF TORNADIC STORMS BY THE WRF MODEL WITH DIFFERENT FORECAST LEAD TIME AND INITIAL CONDITIONS

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Scientific challenge

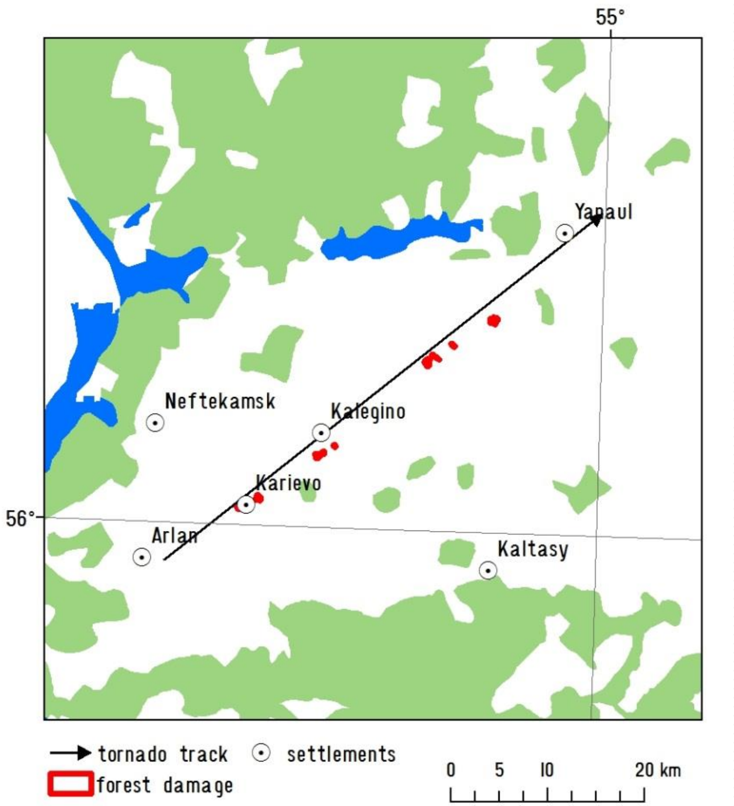
- Many research teams in the U.S, Europe and Russia studied the possibility of explicit simulation and short-term forecasting of tornadic storms with the use of mesoscale atmospheric models (commonly, the Weather Research and Forecasting (WRF)) model. However, the simulation results are often unsatisfactory in terms of simulated storm intensity, spatial and time accuracy.
- We considered the possibility of short-term forecast of three strong (F2-F3) tornado events in the Ural region (29 Aug 2014, 3 June 2017 and 18 June 2017)

Purpose of the study

- Estimate the influence of forecast lead time (12, 24 or 36 h), and the initial conditions (GFS forecast or ECMWF ERA-5 data) on the accuracy of simulation of tornadic storms

29 Aug 2014 EF3 tornado in Bashkortostan

Date	Start point	End point	Data sources	Path length (km)/ maximum width (m)	F-scale intensity	Damage to settlements and infrastructure	Forest damage area, ha
29.08. 2014	55.98 N 54.36 E	56.26 N 54.95 E	Eye-witnesses damage reports, forest damage	47/0,6	F3	2 fatality, 76 injured, 600 houses damaged, >80 houses totally destroyed	143



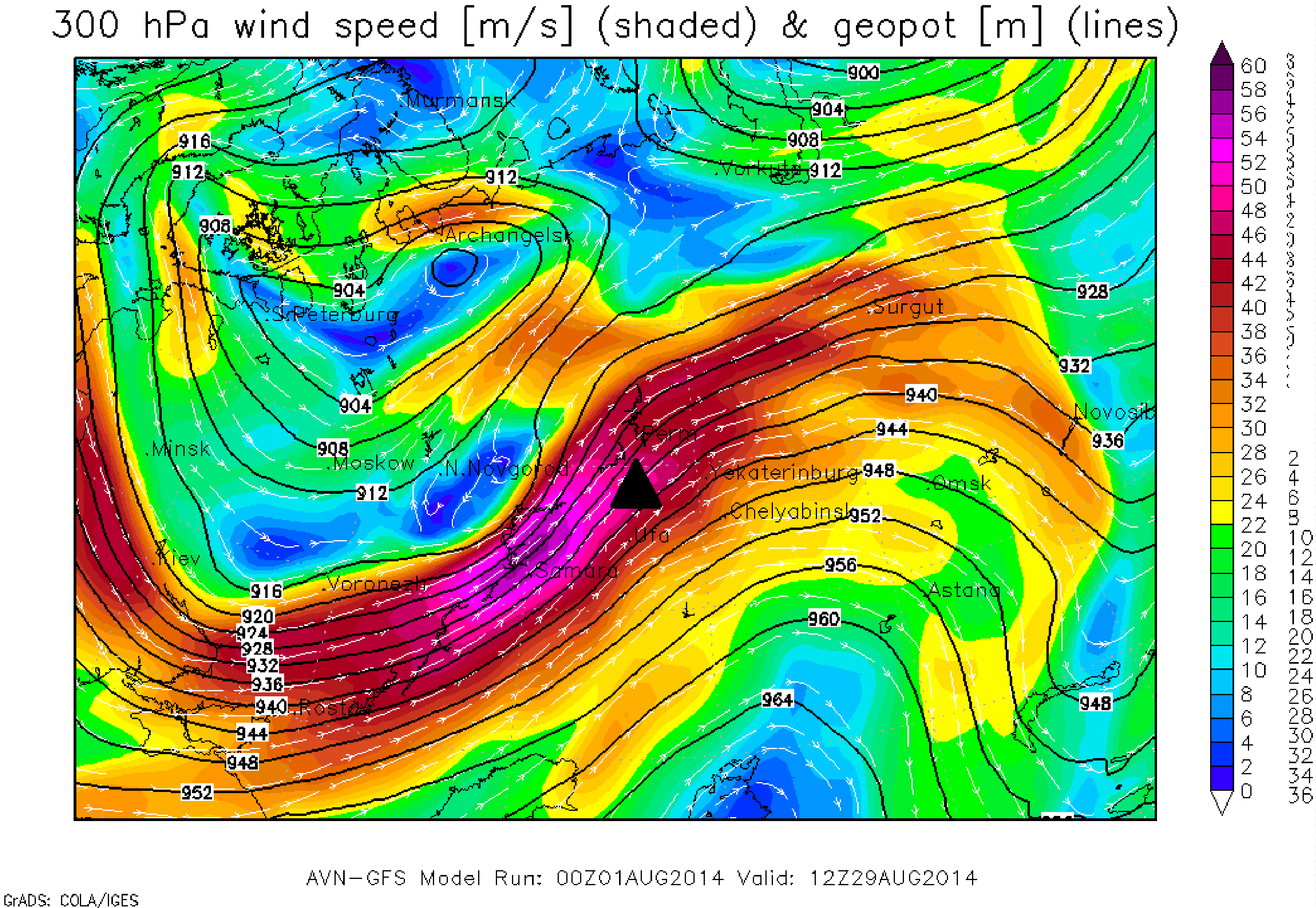
3 June 2017 severe weather outbreak (Sverdlovsk region)

Location	Time (UTC)	Type of event	Data sources	Intensity	Damage to settlements and infrastructure	Forest damage track	
						Length (km), average and maximum width (m)	Damaged area, ha
57.24 N; 59.32 E (Staroutkinsk town)	11.15	tornado	Eye-witnesses and damage reports, forest damage	F2	Dozens of houses damaged, roofs destroyed	19,8/140/380	114
57.64 N; 59.44 E (near Visim town)	11.45	tornado	forest damage	F2	There is no damage in settlements	20,5/248/585	440
58.05 N; 60.04 E (Nizhniy Tagil city)	13.00	squall	Weather station, eye-witnesses and damage reports, forest damage	26 m/s	1 fatality, up to 10 injured, estimated damage more than $3 000 000	Local windthrows	192
58.81 N; 59.52 E (near Kachkanar town)	14.30	Downburst, large hail	Eye-witnesses reports, forest damage	No data	Damage to houses (roofs destroyed)	10,7/420/1650	382

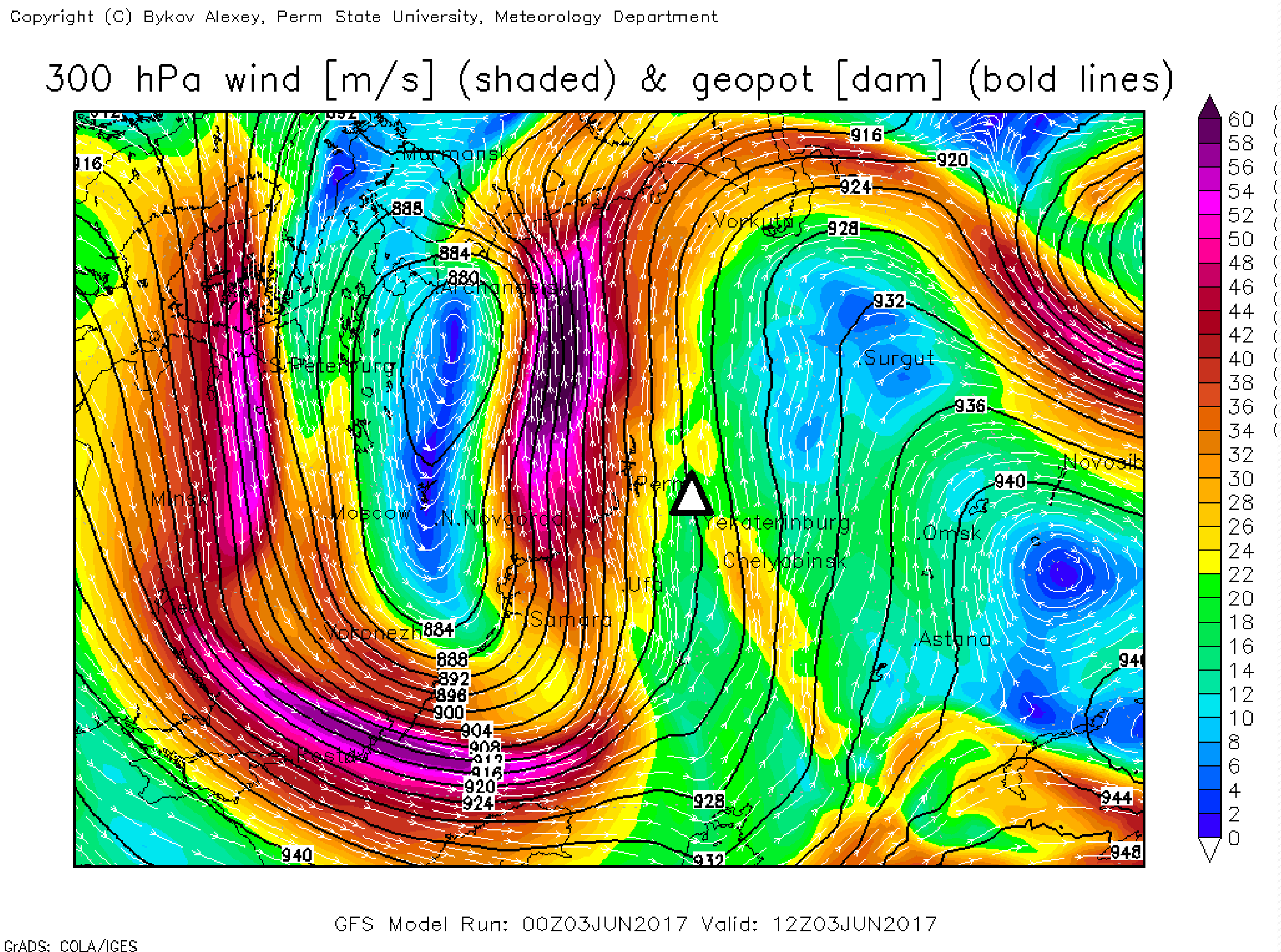
18 June 2017 severe weather outbreak (Kurgan region)

Location	Time (UTC)	Type of event	Data sources	Intensity	Damage to settlements and infrastructure	Forest damage track	
						Length (km), average and maximum width (m)	Damaged area, ha
55.16 N, 66.53 E Tsentral'noye village)	11.00	tornado	Eye-witnesses reports	No data	There is no damage in settlements	There is no forest damage	
55.29 N, 66.30 E (Kravtsevo village)	11.15	tornado	Eye-witnesses and damage reports	F1	Damage to houses (roofs destroyed)	There is no forest damage	
55.58 N, 66.61 E (Maloye Pes'yanovo village)	11.45	tornado	Eye-witnesses and damage reports, forest damage	F3	Several people injured; 25 houses damaged, 4 totally destroyed	28,4/245/1200	340
56.48 N, 66.46 E (Tumen' region)	13.00	tornado	forest damage	F1	There is no damage in settlements	2,2/126/300	30

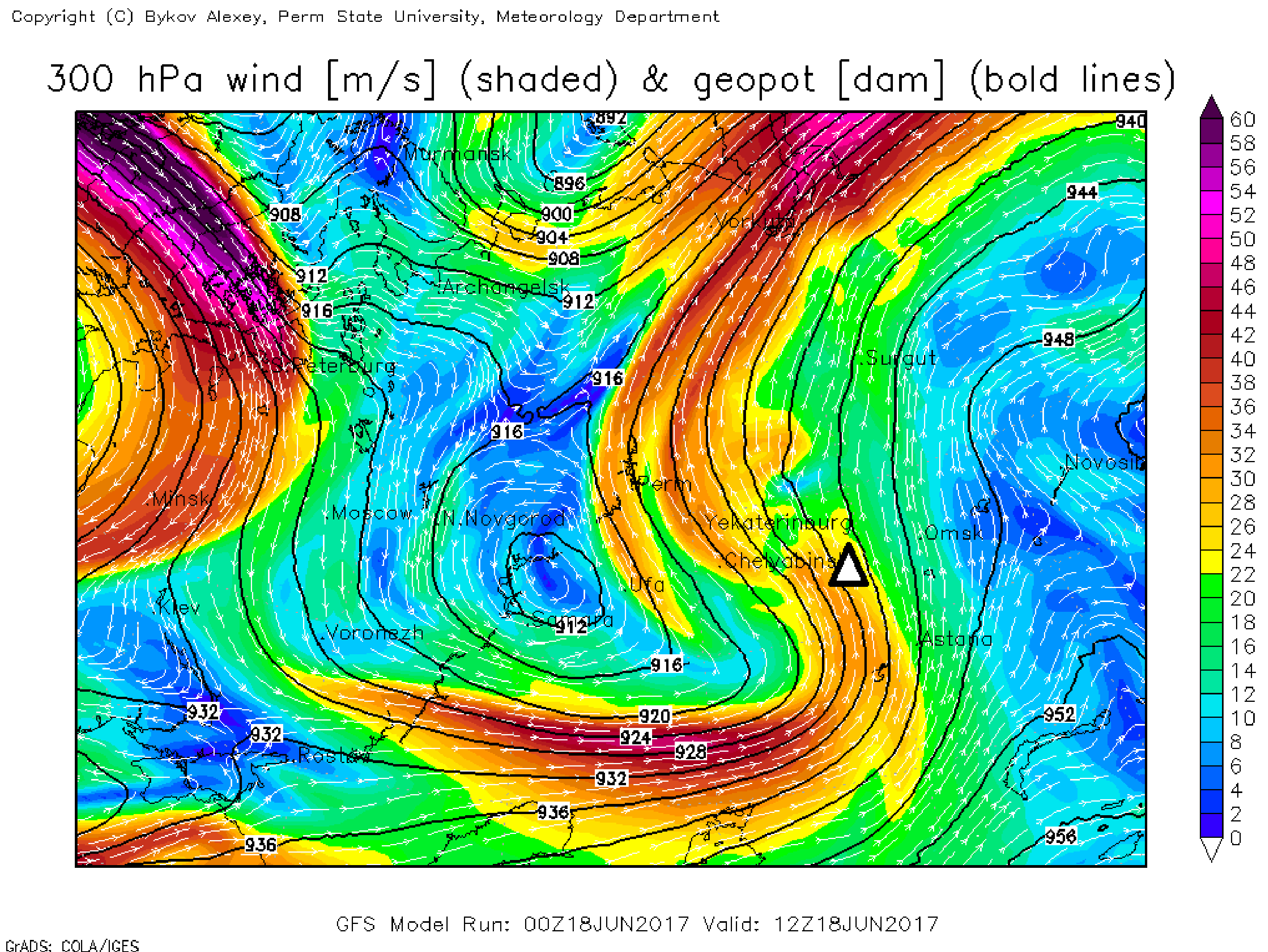
Synoptic-scale environments (29 Aug 2014)



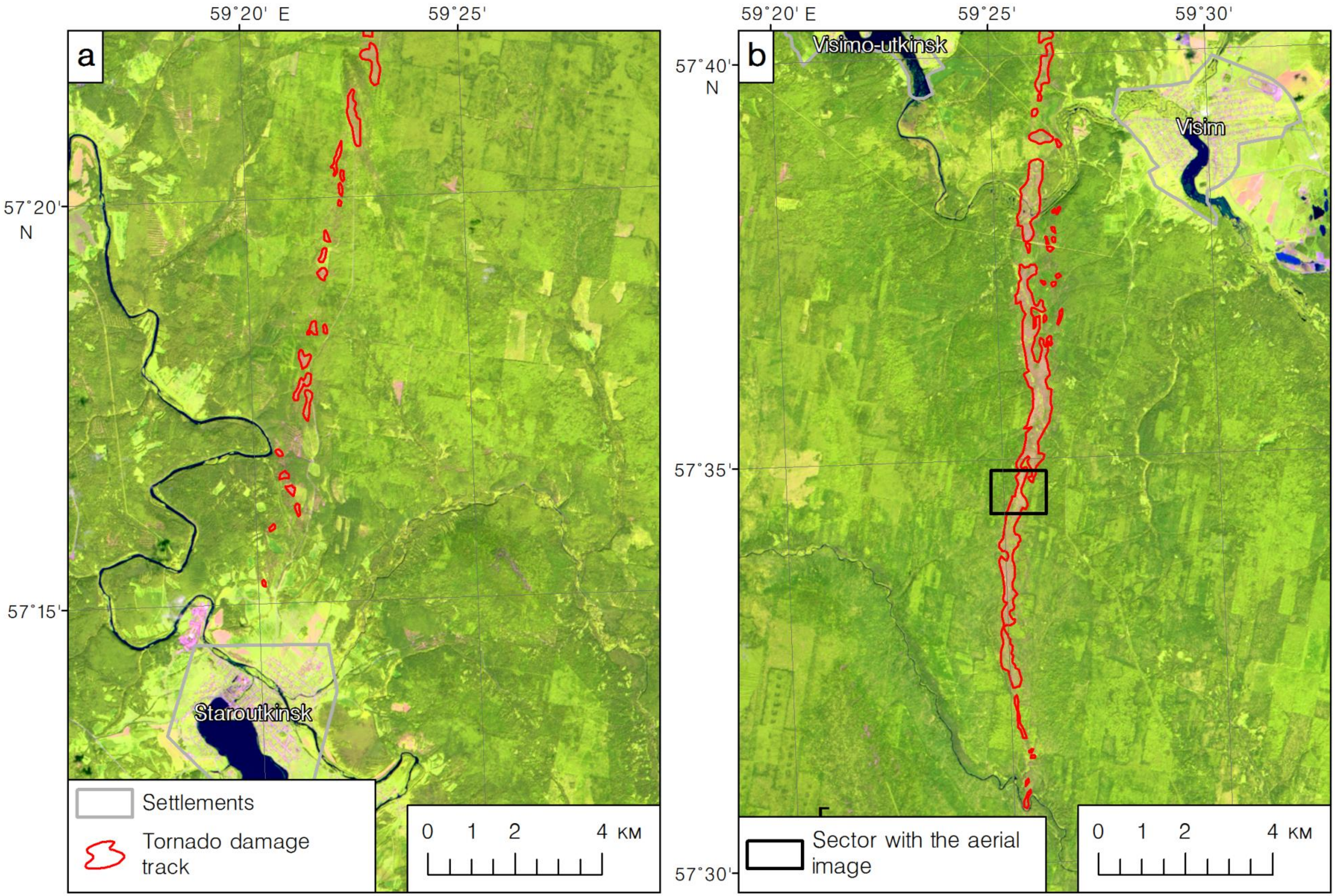
Synoptic-scale environments (3 June 2017)



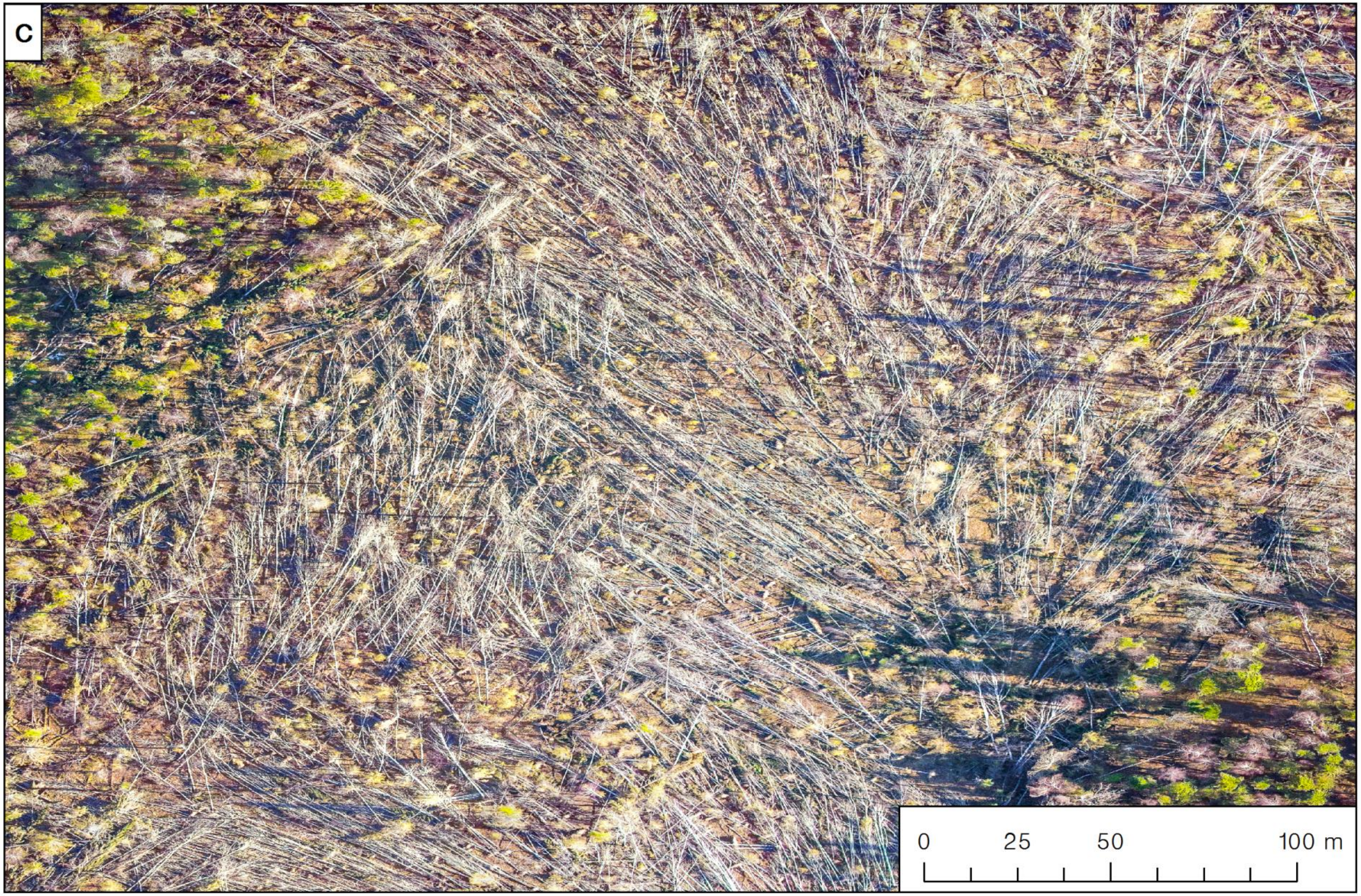
Synoptic-scale environments (18 June 2017)



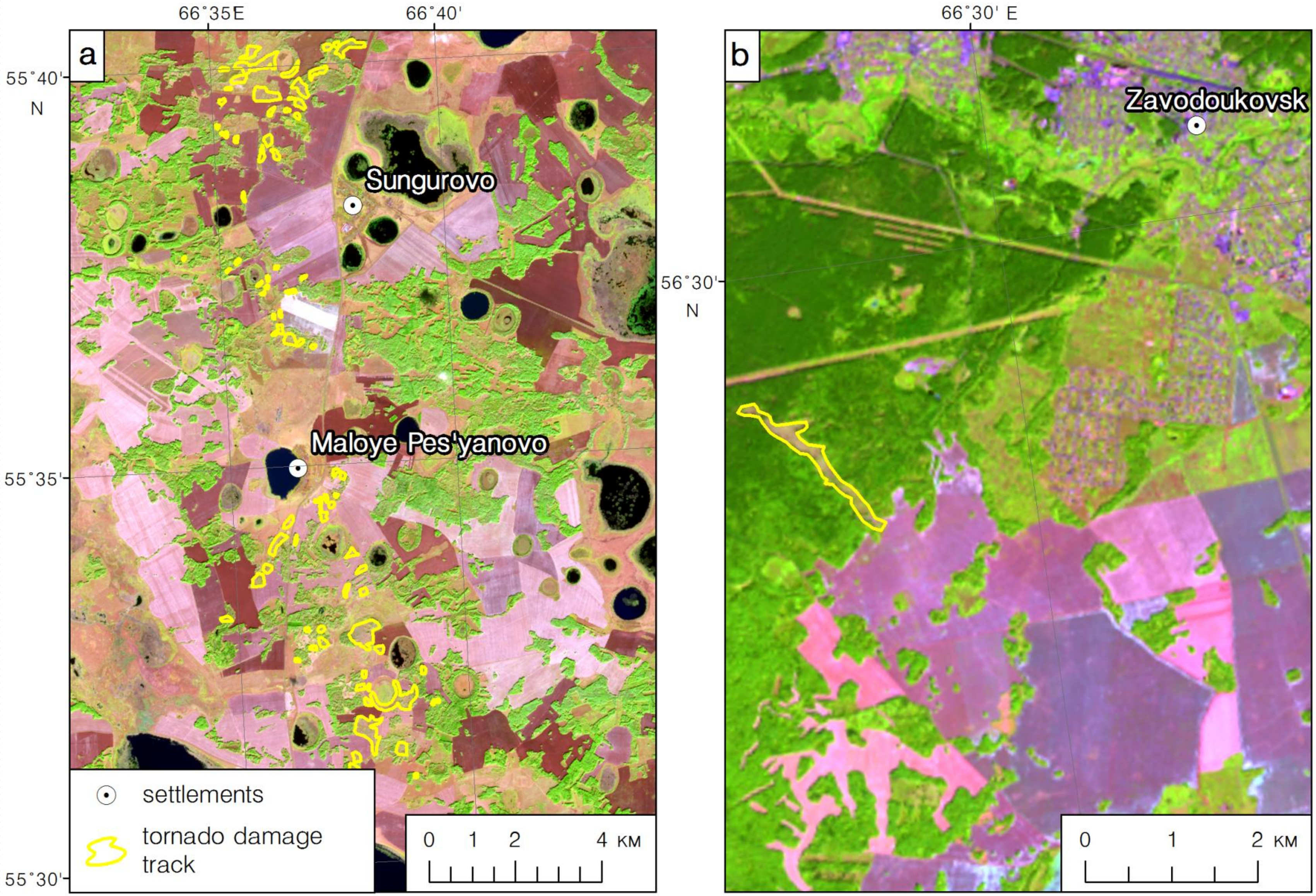
Tornado tracks in forest (3 June 2017)



Forest damage near Visim settlement 3 June 2017



Tornado outbreak 18 June 2017



WRF model settings

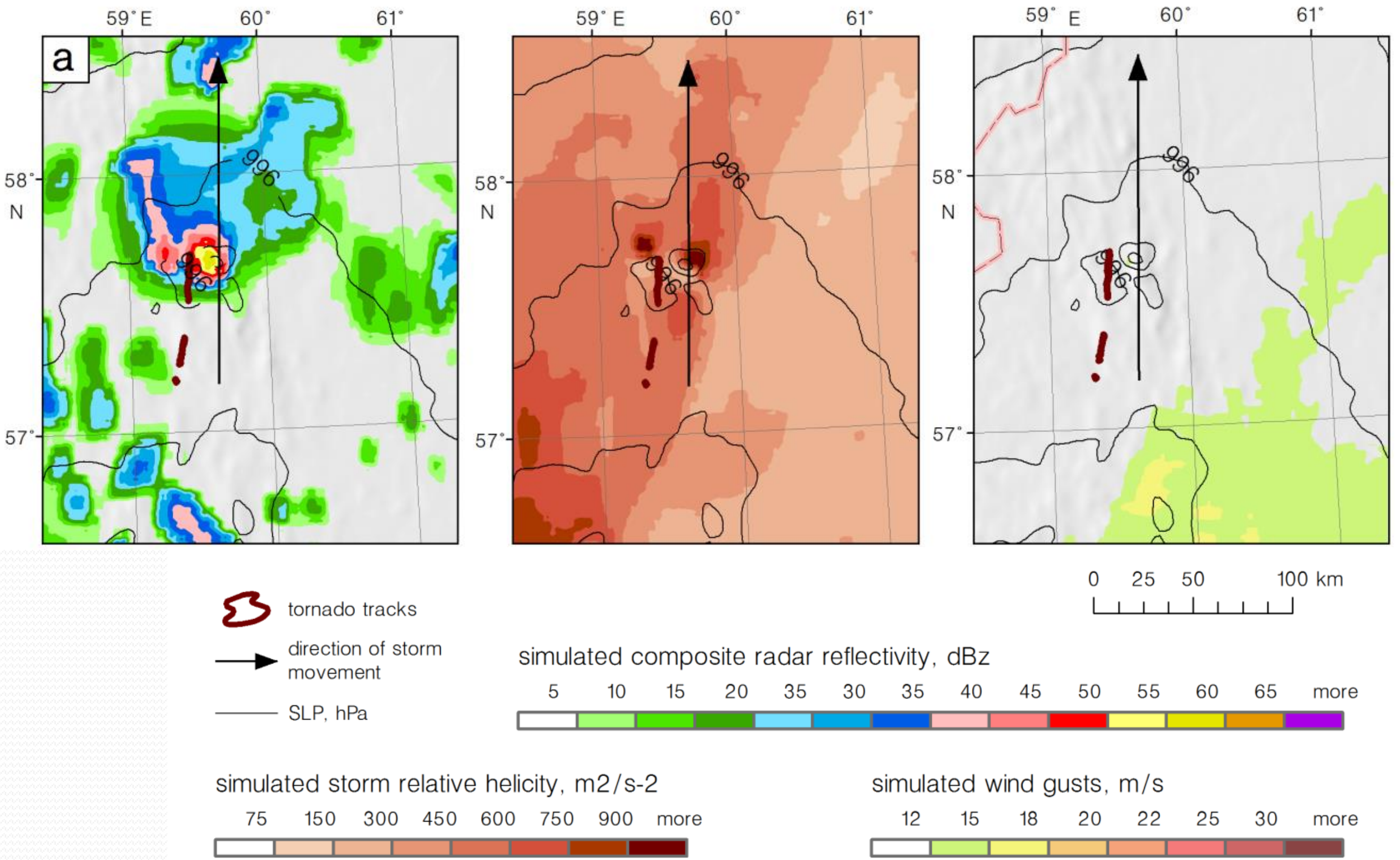
Model characteristic	Setting
Horizontal grid resolution and grid points	7,2 km/278×278 (without nested grid)
	3 km/600×600 (without nested grid)
	9 km/333×333, with one nested grid (3 km/400×400)
Number of vertical layers (up to 5000 mb)	38
Topography	U.S. Geological Survey (USGS) DEM (30s)
Simulation length	27 h
Output data time step	1 h
Dynamics	Non-hydrostatic
Model core	Advanced Research WRF (ARW), non-hydrostatic
Integration time step	48 or 18 seconds
Initial and lateral boundary	0,25˚ GFS forecast
Microphysics schemes	Thompson scheme
Planetary Boundary Layer (PBL) scheme	Yonsei University scheme
Land surface physics scheme	Noah Land Surface Model
Long and short wave radiation scheme	Rapid Radiative Transfer Model (RRTM)
Surface layer scheme	Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions
Convection	Explicit (cloud-resolving) modeling

WRF model forecast of supercell storms 03.06.2017 and 18.06.2017 with 12 h lead time, and comparison with Meteosat data

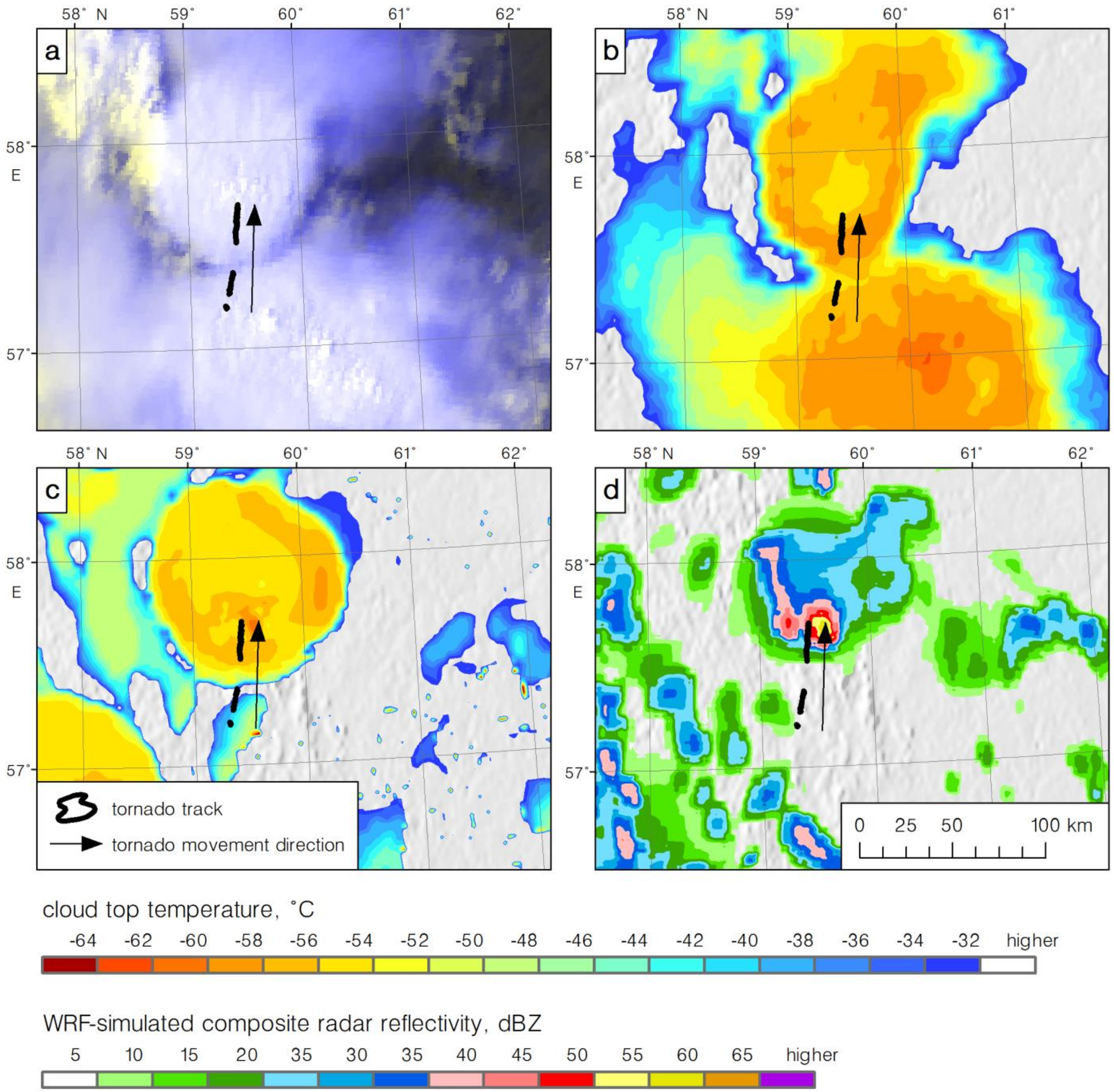
Date, time (UTC)	Model grid size, km	WRF-simulated supercell storms parameters (maximum values in 50-km radius around tornado track)		
		0–3 km storm relative helicity (SRH), $m^2 \cdot s^{-2}$	Composite reflectivity, DBZ	Wind gust speed, m/s
03.06.2017, 11.00 – 12.00	7,2	1200	42	13
	3	1075	58	13
	3 (with one nested grid)	770	47	-
18.06.2017, 12.00 – 13.00	7,2	610	56	23
	3	1200	64	31
	3 (with one nested grid)	990	58	31

Date, time (UTC)	Model grid resolution, km	Minimum cloud top temperature, °C (Meteosat-8 data/ WRF model forecast)	Distance between actual and simulated storm track, km	Time error, h
03.06.2017, 11.00 – 12.00	7,2	–62/–61	40	+1,25
	3	–62/–61	10	0
	3 (with one (nested grid)	–62/–62	0	–0,5
18.06.2017, 11.00 – 12.00	7,2	–64/–62	35	+1,5
	3	–64/–64	10	+1,5
	3 (with one (nested grid)	–64/–62	15	+2,5

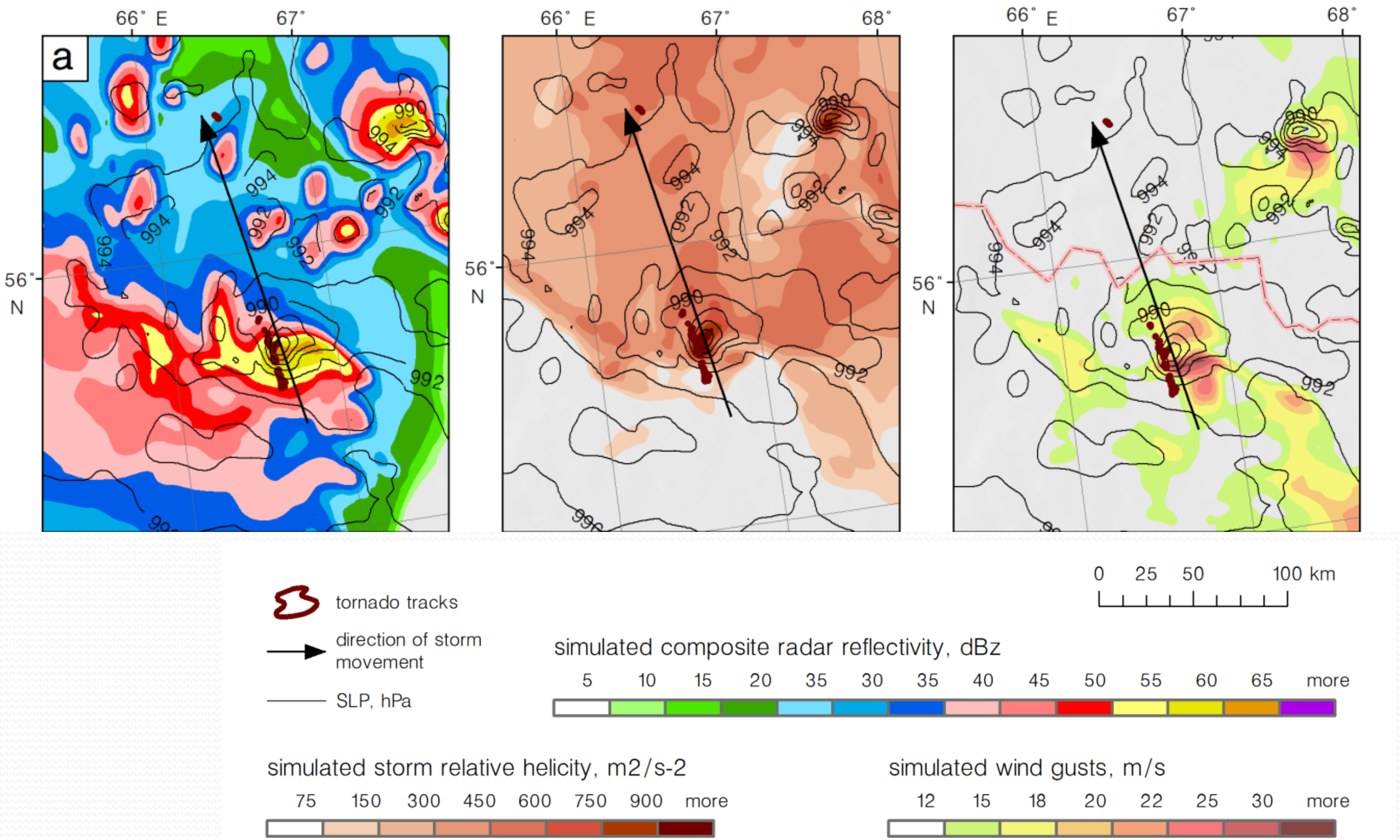
WRF model forecast of tornadic storm 3 June 2017 with 3 km grid resolution and 12 h lead time (from 00 h UTC 3 June 2017). Initial data – GFS model forecast



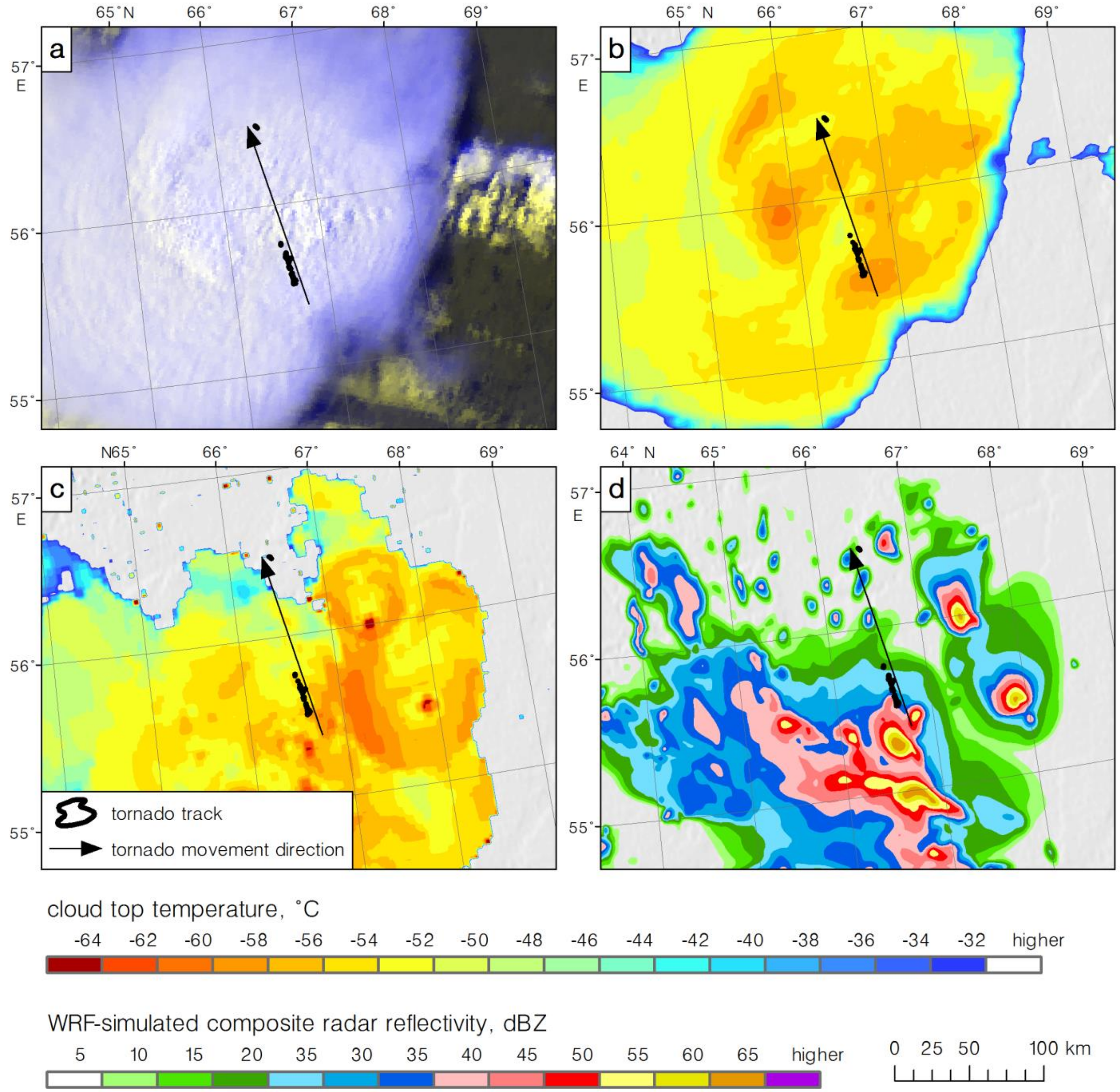
HRV cloud RGB image (a) and cloud top temperature (b) by Meteosat-8 data; WRF-simulated cloud top temperature (c) and composite reflectivity (d) at 12.00 UTC 3 June 2017. Initial data – GFS model forecast from 00 UTC 3 June 2017



WRF model forecast of tornadic storm 18 June 2017 with 3 km grid resolution and 12 h lead time (from 00 h UTC 18 June 2017). Initial data - GFS model forecast



HRV cloud RGB image (a) and cloud top temperature (b) by Meteosat-8 data; WRF-simulated cloud top temperature (c) and composite reflectivity (d) at 12.00 UTC 18 June 2017. Initial data – GFS model forecast from 00 UTC 18 June 2017

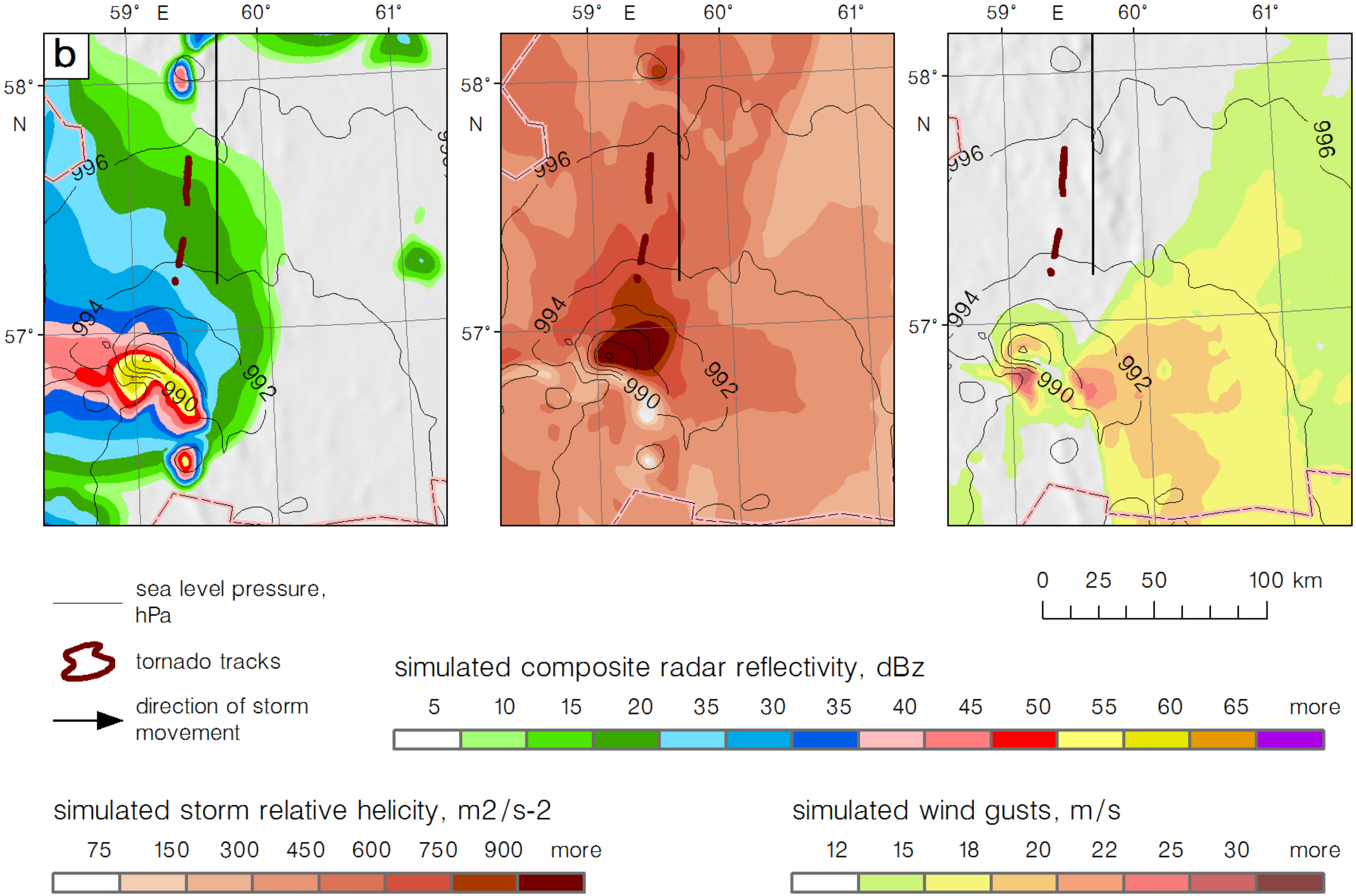


WRF model forecast of supercell storms 03.06.2017 and 18.06.2017 with 24 h and 36 h lead time, and comparison with Meteosat data

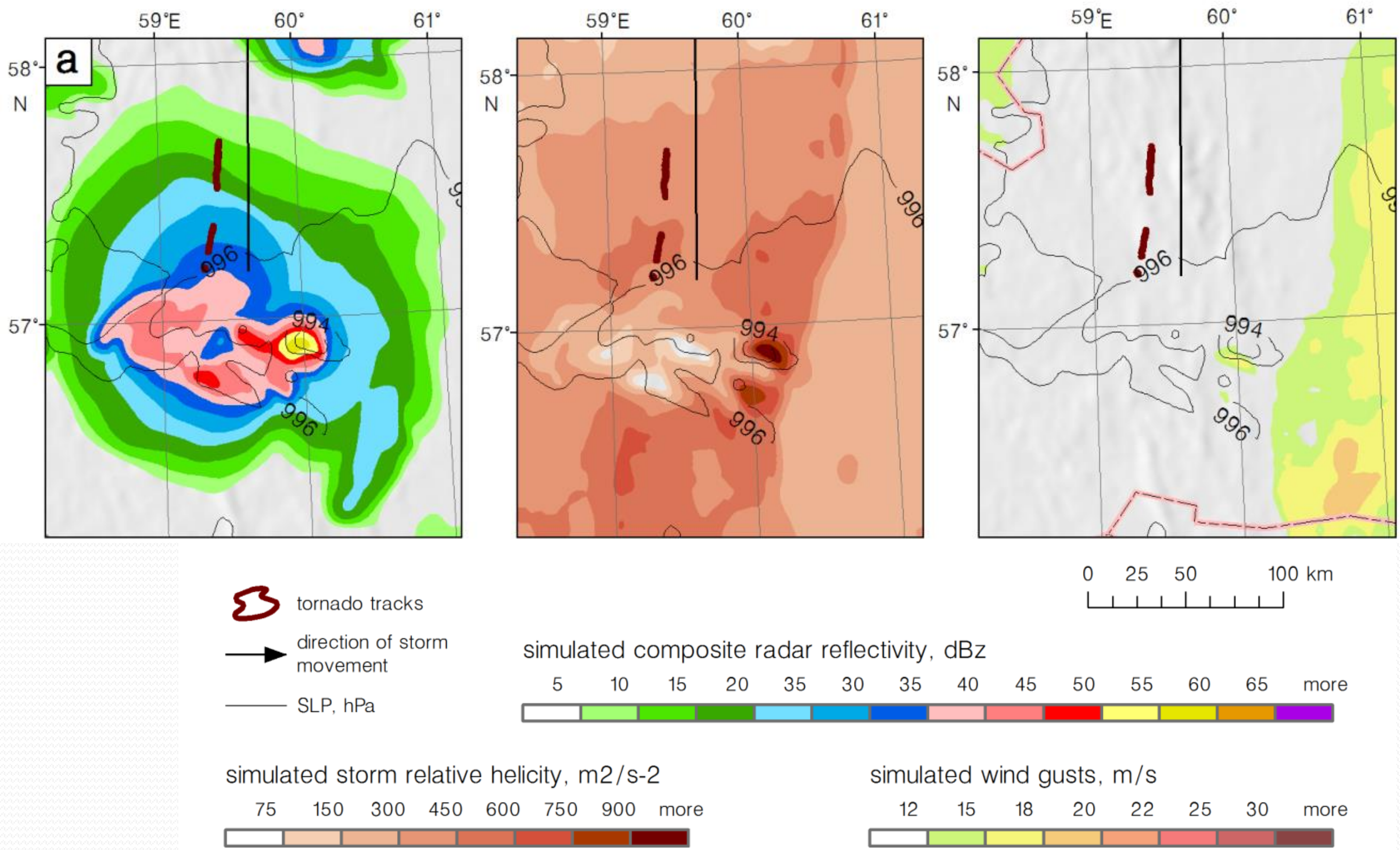
Date, time (UTC)	Model start date and time (UTC)	WRF-simulated supercell storms parameters (maximum values in 50-km radius around tornado track)		
		0–3 km storm relative helicity (SRH), $m^2 \cdot s^{-2}$	Composite reflectivity, DBZ	Wind gust speed, m/s
03.06.2017, 11.00 – 12.00	02.06.2017, 00.00	1000	57	17
	02.06.2017, 12.00	1350	60	28
18.06.2017, 12.00 – 13.00	17.06.2017, 00.00	600	52	30
	17.06.2017, 12.00	400	57	23

Date, time (UTC)	Model start date and time (UTC)	Minimum cloud top temperature, °C (Meteosat-8 data/ WRF model forecast)	Distance between actual and simulated storm track, km	Time error, h
03.06.2017, 11.00 – 12.00	02.06.2017, 00.00	–62/–61	50	+1,25
	02.06.2017, 12.00	–62/–64	15	+1,5
18.06.2017, 11.00 – 12.00	17.06.2017, 00.00	–64/–61	50	+1,25
	17.06.2017, 12.00	–64/–62	35	+1,0

WRF model forecast of tornadic storm 3 June 2017 with 3 km grid resolution and 24 h lead time (from 12 h UTC 2 June 2017). Initial data – GFS model forecast



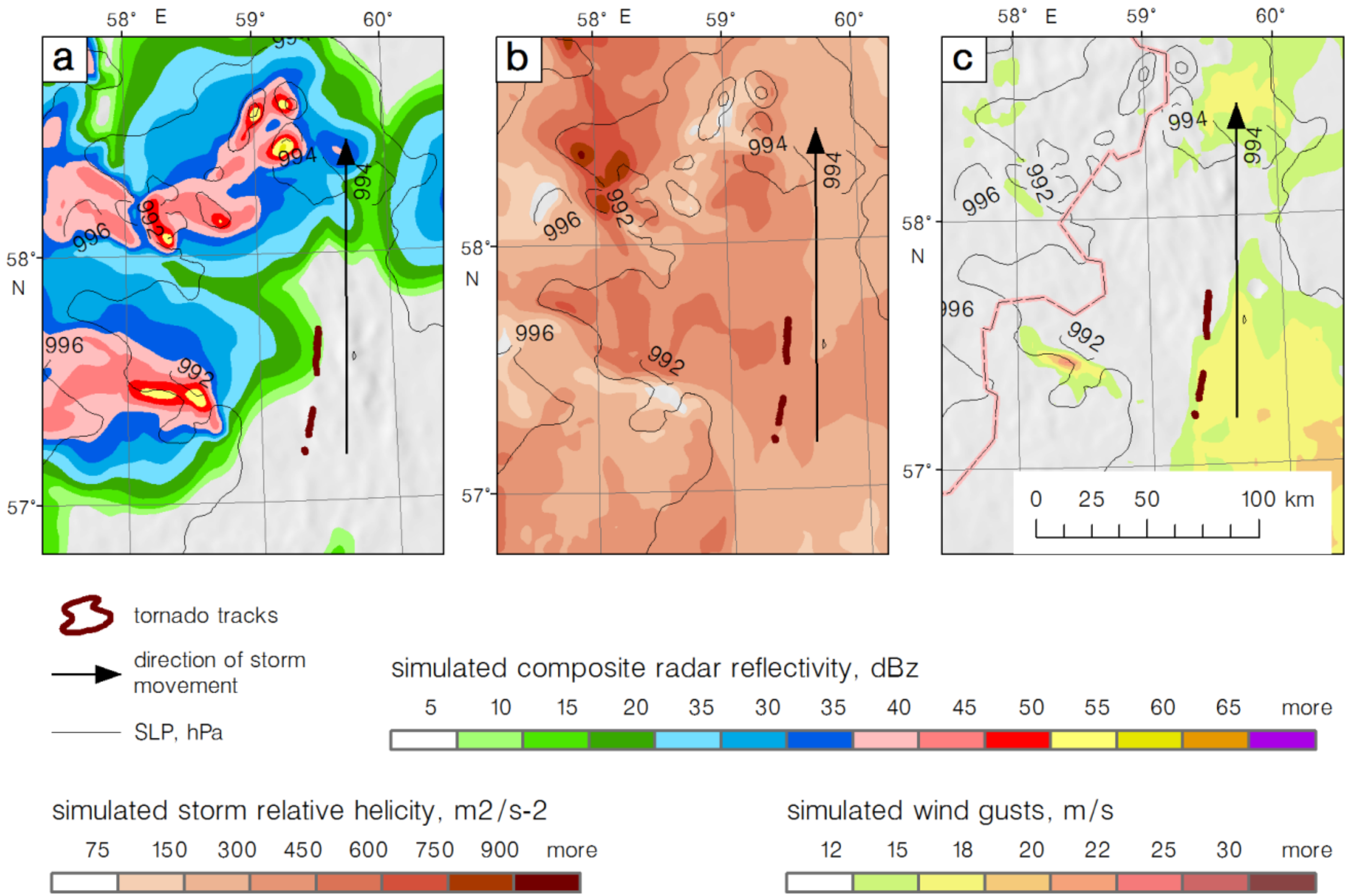
WRF model forecast of tornadic storm 3 June 2017 with 3 km grid resolution and 36 h lead time (from 00 UTC 2 June 2017). Initial data – GFS model forecast



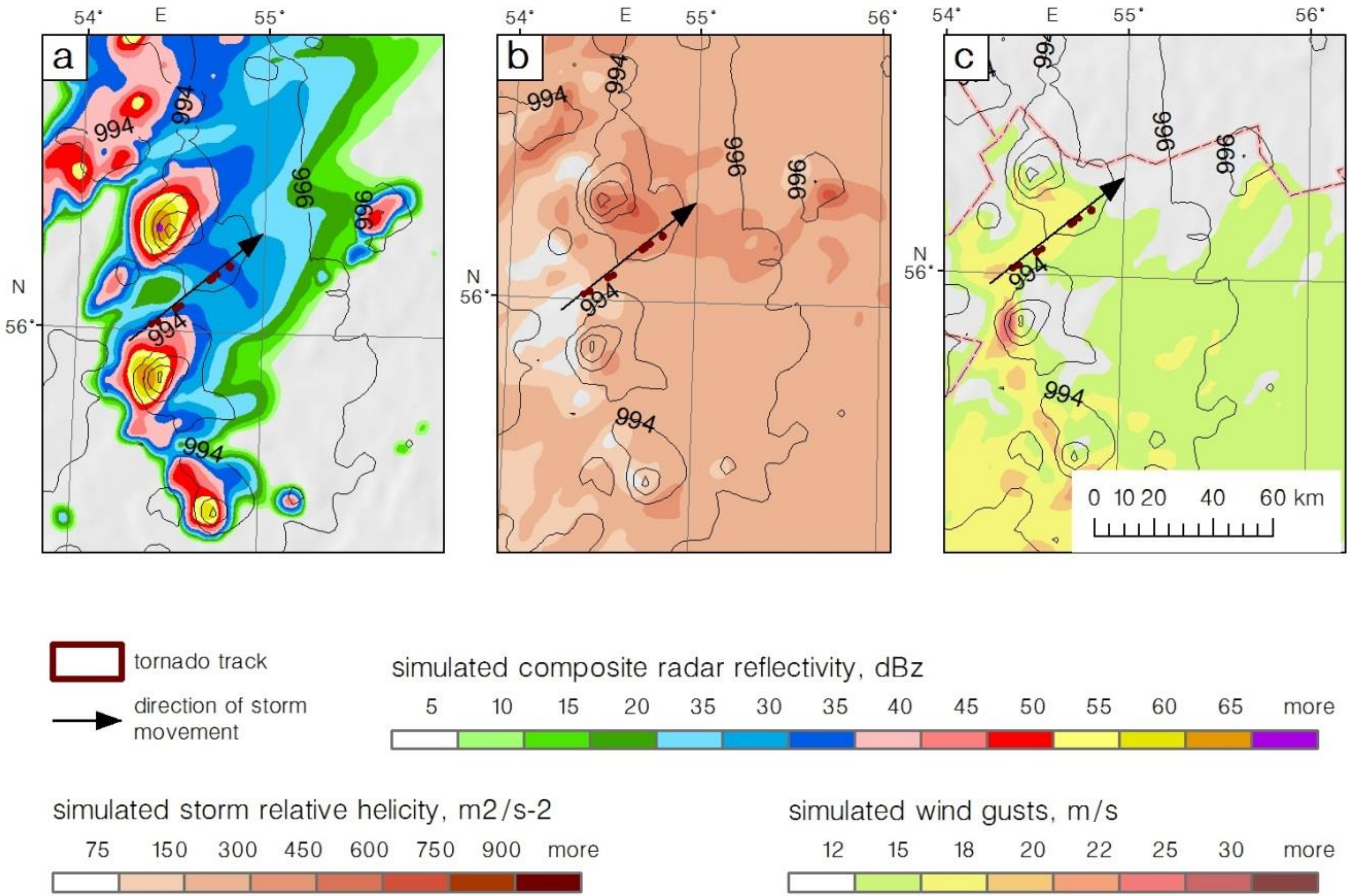
Experiments with ECMWF ERA-5 initial data

- Two tornadic storms (29 Aug 2014 and 3 June 2017) are additionally simulated by the WRF model with the use of ECMWF ERA-5 initial data
- WRF model grid resolution is 3 km, forecast lead time – 18 h.
- The simulation results are compared with the same, obtained with the use of GFS model initial data

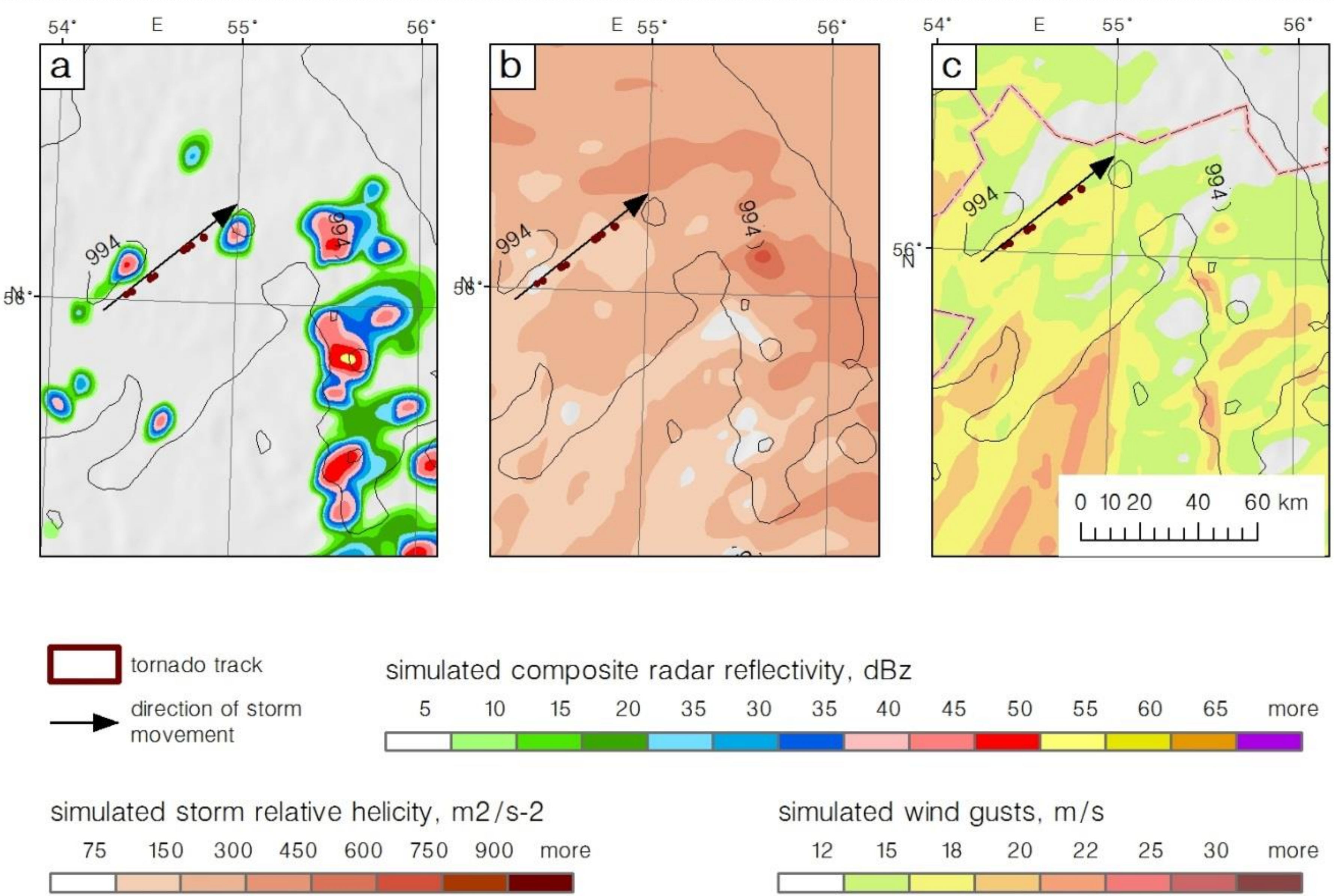
WRF model forecast of tornadic storm 3 June 2017 with 3 km grid resolution and 18 h lead time (from 18 UTC 2 June 2017). Initial data – ECMWF ERA-5 reanalysis



WRF model forecast of tornadic storm 29 Aug 2014 with 3 km grid resolution and 18 h lead time (from 18 UTC 28 Aug 2014). Initial data – ECMWF ERA-5 reanalysis



WRF model forecast of tornadic storm 29 Aug 2014 with 3 km grid resolution and 12 h lead time (from 00 UTC 29 Aug 2014). Initial data – GFS model forecast



Conclusion and future studies

- The WRF model with GFS initial data successfully reproduced two out of three studied supercell storms with strong tornadoes (3 June 2017 and 18 June 2018). Low-level mesocyclones (with a deepness ~ 10 hPa in the SLP field), high values of composite reflectivity (>55 dBz), extremely high storm-relative helicity (SRH >1000 m^2/s^{-2}) and wind gusts > 25 m/s are reproduced by the model.
- The effect of forecast lead time on the accuracy is ambiguous. For example, the tornadic storm 3 June 2017 was successfully simulated with 24 h lead time, but its intensity was substantially underestimated by the 12-h forecast. In the same time, the most accurate forecast of tornadic storm 18 June 2017 was obtained with 12 h lead time.
- The ECMWF ERA-5 initial data can improve the forecast accuracy, in comparison with GFS model data (on example of tornadic storm 29 Aug 2014). Additional studies will be conducted on this issue. Also, it is necessary to estimate the frequency of false alarms in the forecast of supercell storms.

Thank you for your attention

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